CEMENT AND LIME MANUFACTURE

Vol. XXIV. No. 1 — JANUARY 1951 — Price 1s. Annual subscription 6s. ($1·30 in Canada and U.S.A.)

Published by Concrete Publications Ltd. 14, Dartmouth Street, London, S.W.1

CEMENT AND LIME
MANUFACTURE

PUBLISHED ALTERNATE MONTHS. PRICE 1/- A COPY. ANNUAL SUBSCRIPTION 6s. POST FREE. $1·30 IN CANADA AND U.S.A.

PUBLISHED BY
CONCRETE PUBLICATIONS LIMITED
14 DARTMOUTH STREET, LONDON, S.W.1

TELEPHONE: WHITEHALL 4581.
TELEGRAPHIC ADDRESS:
CONCRETIUS, PARL. LONDON.

PUBLISHERS OF
"CONCRETE & CONSTRUCTIONAL ENGINEERING"
"CONCRETE BUILDING & CONCRETE PRODUCTS"
"CEMENT & LIME MANUFACTURE"
"THE CONCRETE YEAR BOOK"
"CONCRETE SERIES" BOOKS.

VOLUME XXIV. NUMBER 1. JANUARY, 1951

A Rotary Lime Kiln.

AFTER discussing the performance of vertical lime kilns, Mr. Victor J. Azbe describes in "Rock Products" for March 1950 a suggestion for a rotary kiln for burning lime. The main features of the plant (*Fig.* 1) are as follows.

The kiln is short and compact and of high capacity with 20 to 25 cu. ft. of internal volume per ton of output. For 240 tons capacity a kiln 120 ft. long and 8 ft. internal diameter would suffice, and for 75 tons a kiln need only be 80 ft. long by 5 ft. internal diameter. The reduction in size over kilns commonly used is mainly due to greatly increased internal heat absorption area. It is also due to residual calcination and terminal cooling of gases being accomplished outside the rotary portion of the system.

The installation has about 60 per cent. thermal efficiency, requiring 4,500,000 B.T.U. per ton of high-calcium lime. The distribution of the remaining heat losses is as follows: Due to products of combustion at 750 deg. F., 13 per cent.; Due to escaping CO_2 from stone, 3 per cent.; Due to H_2O from combustion of hydrogen, 5 per cent.; Due to hot lime and lime-cooler radiation, 5 per cent.; Due to excess air or incomplete combustion, 3 per cent.; Due to kiln radiation, 6 per cent.; Miscellaneous and unaccountable, 5 per cent.; Total, 40 per cent. The waste-gas temperature is within 50 deg. F. of the theoretical temperature corresponding to the thermal efficiency. This is possible by reducing delayed combustion in the preheating zone and increasing the heat-transfer area and heat-transfer rate in the kiln, and is due to rapid terminal cooling when the escaping gases are brought into direct contact with the entering stone for a short period. The arrangements for terminal cooling tend also to filter the gases, reducing the loss to the dust chamber and the stack and returning it to the kiln.

The kiln is equipped with a stationary sectionalized and pressurized chamber. The upper part of this chamber is the finishing zone. Lime is discharged from the kiln to include a portion that is completely burned and very hot (that part of the charge which calcines most readily in the rotary kiln). With this portion

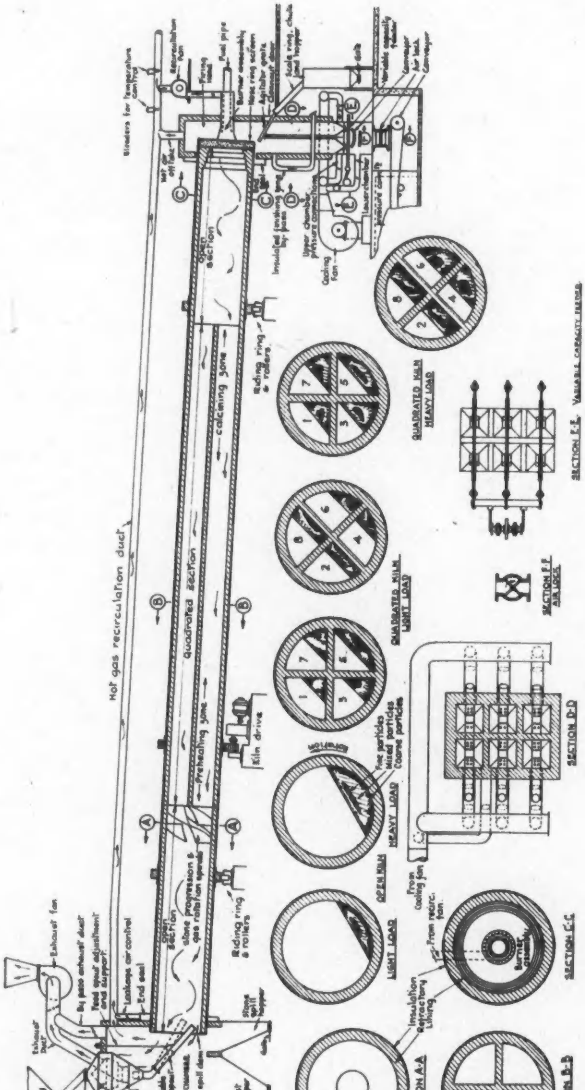


Fig. 1.—Suggestion for a Rotary Lime Kiln.

there is a portion which is more resistant to calcination and which is usually the smaller size stone to which heat has not ready access in the rotary portion of the system. The sensible heat of the completely burned portion is transferred to the incompletely burned portion, accomplishing full calcination. Some air is allowed to pass through this upper chamber to reduce CO_2 pressure and the calcination temperature, which then is reduced to 1,300 deg. F. As much as 10 per cent. of lime may be so calcined, which ordinarily would require 20 to 30 per cent. of the length of the kiln ; but even if it were no more than 2 or 3 per cent. the advantage still would be great, as complete terminal calcination in the case of most rotary kilns is impossible. The upper sections of the chambers constitute a "finishing zone," completing the calcination and only partially cooling the lime, by the use of sensible heat for calcination and by very limited passage of air.

The lower portions of the stationary chambers constitute the "recuperative lime cooler," through which a sufficiently large amount of air passes, under pressure, to cool the lime completely. Most of this air, on the way to the kiln, by-passes the upper finishing portion of the chambers, wherein the aim is to keep the lime hot as long as possible to complete residual calcination. The cooling is fully recuperative. Nearly all the heat is regained as the wall surface exposed is limited, of substantial thickness, and insulated. This almost complete recovery of the sensible heat of the lime is the most important of the several factors conducive to the results claimed.

The kiln has a relatively low temperature peak. In ordinary kilns maximum temperatures are usually up to 3,000 deg. F. because heat is generated faster than it is absorbed. In the case of the rotary kiln described, the aim is not to achieve complete calcination within the rotary section, and the heat absorption surface of the refractory insertions in the hotter portion of the kiln is about three times as great and amounts in total effectiveness to four or five times that of an ordinary open rotary kiln. In view of this, and since the peak temperature is not greater than 2,500 deg. F., refractory, scale adhesion, and ring problems are unlikely to occur. A kiln of such low temperature permits complete insulation without fear of refractory failure. Also, radiation loss is reduced to 5 per cent.

The insertions mentioned tend to destroy the sliding action and size segregations and to bring the smaller fractions of the stone repeatedly in contact with the flame or with the hot wall. Further, the "fines" that may not be calcined within the kiln are calcined in the stationary finishing sections of the cooler. In view of this the kiln permits a wide range in the feed size, and possibly use of the entire unscreened crusher discharge, without reducing capacity or causing poor quality. The plan is for the utmost conservation of heat, with emphasis on the highest attainable capacity and quality of lime. To augment this a system of hot gas recirculation is introduced. Return of waste gases as hot as are obtainable, their use in the mill, operation of the mill at much higher temperatures due to the presence of CO_2, and the use of some of the recirculating gases for fuel injection,

flame projection and distribution control, are aids to higher thermal efficiency and improved capacity.

Flow of Material.

The stone enters the " static stone preheater," where it is retained for a short period in contact with the escaping gases. Its purpose is to cool the gases by direct contact of the gas and the solids, and to remove suspended dust. The gas passes through a stone-bed of limited and uniform thickness so as to assure suitable gas distribution. From the cooler the stone passes into the kiln through an adjustable feed pipe. The kiln is open (for its initial length), then the stone enters the " progression section " consisting of deep spirals which tend to move the stone forward as well as to give the gases a rotary action, aiming to scrub the remaining surfaces of the stone for better preheating and projection of the coarser portion of the dust through centrifugal action to the wall of the kiln and the surfaces of the stone. Following this is the hotter and more active part of the kiln divided by means of refractory blocks into several sections. This divides the stone and the gas into several streams, thus increasing the surface exposed to the gases. The most important advantage of this sectionalising is that in addition to the increase of heat transfer surface the segregated fines become exposed repeatedly during each revolution. The quadrants extend into the hottest section of the kiln as it is essential that the rate of heat absorption be brought into step with the rate of heat generation. The kiln is open for a short distance beyond the edge of the quadrant section. Within this open section mixing of air with the combustibles and ignition and precombustion take place together with some heat absorption.

At the outlet of the kiln is a dam to retain the lime within the open section and to constrict the gas-air inlet and so permit more complete and rapid mixing, quicker ignition, and temperature increase, all of which are desirable since the lime should be kept hot until calcination is completed in the finishing zone. The lime may discharge over the dam in a stream directly into the " secondary calcining section " of the " recuperative unit," or it may pass through an activated grate to a bin.

At this point the lime is not completely calcined. The " secondary calciner " utilizes the sensible heat of the over-hot lime to complete the calcination of the remainder. As much as 10 per cent. of the total calcination can be accomplished in this way, whereas an ordinary kiln absorbs 30 per cent. of the effort. The purpose of this unit is to complete calcination and to cool the lime, and the system is in two stages. The system is cellular, consisting of several small units from which discharge as well as air admission can be independently controlled. The system is divided vertically as well as horizontally. A large amount of air is passed through the lower sections to accomplish complete cooling, most of this air being by-passed to the kiln. Only a small amount of air passes through the upper sections, and this is gauged to give the lowest CO_2 concentration and therefore the most ready calcination. A by-pass air-damper is regulated so

that lime passes into the cooling section at a temperature of 1,400 deg. F. The base of the "recuperative cooler" is pressurized and air-sealed.

The burner is a wide-angle arrangement with the fuel surrounded concentrically by the conditioning stream consisting of the re-circulating gas and a small proportion of air. This emerges from the tip of the burner in a rolling flow of wide angle, filling the cross section of the choked kiln opening. The hot air from the cooler is induced into this active swirling stream and equally distributed.

The portion of the combustion process completed in the open section is sufficient only to take care of the heat abstracted and to raise the temperature to the desired point. The remainder of the combustion takes place within the quadrants. Because the mixtures are more intimate and gaseous stratifications much less, with far greater turbulence, combustion in such a quadrated kiln would be completed considerably earlier than in an open kiln, since there is at least three times the heat-transfer surface available; this is equal in actual effectiveness to four to five times that of an open kiln.

Temperature Gradient.

Unless the stone is wet, and even if the kiln operates at the relatively high thermal efficiency of 60 per cent., the temperature of the escaping gases leaving the "static stone preheater" will be between 600 and 700 deg. F. The entering gases will have considerably higher temperature. Therefore, considerable preheating is accomplished, even though surface exposure is limited, because the temperature difference between the stone and gases is high and contact intimate. In the open section preheating is much slower, but it is aided by the rotating flow of the gas-stream and also by wall insulation. After the stone enters the quadrants its preheating is far more rapid, and the cooling of the gases is also more rapid, but the largest amount of work does not take place until the partially-burned stone enters the section of the quadrants where combustion is still taking place and where heat transfer is by carbon radiation as well. Radiation heat transfer is proportional to the fourth power of temperature difference, and because in this kiln system the temperature of the gas is less, the tendency is to lower radiation transfer. This is offset by the fact that the surface is much greater, the general temperature of the exposed surface is lower, and a large gas stream is being divided into four smaller streams. These factors tend greatly to increase the rate of radiation transfer. As the lime passes from the quadrant into the open section of the kiln, 80 per cent. of the heat transfer has been completed. Half of the remainder is left for completion in the open section, and the more difficult fraction in the static finishing zone.

In the ordinary open kiln of a given size and fairly heavy load the gas, for each foot length of kiln, would have 22 sq. ft. of projected surface to which heat is transferred, and the material would receive heat from 14½ sq. ft. In the case of a segmented or quadrated kiln of the same size, gas exposure would be 47 sq. ft. or more than double that of the conventional kiln; material exposure would be 37 sq. ft., which is almost three times that of the open kiln. The excess of material

exposure to gas exposure is also an advantage. In the case of an open kiln the wall receiving and giving up heat, due to loss through the wall, would be only partially effective. The quadrant walls are not exposed and any heat imparted to them is utilised. For each part of the revolution of the kiln, heat is absorbed on one side while the other side is being heated. Therefore, the surface is not only greater, but its effectiveness is greater too. The quadrants also increase the kiln load and therefore the kiln time, which is an advantage and, in addition, they tend to bring all of the stone to the surface ; the fines appear at the surface three times in every revolution, while in the case of the conventional kiln they never appear.

A Large Rotary Kiln.

A DRY-PROCESS kiln 350 ft. long by 10 ft. diameter has been installed at the Metaline Falls, Washington, works of the Lehigh Portland Cement Company. The kiln, which is of welded construction, is mounted on five 14 in. tyres turning on water-cooled trunnions, and is erected on a slope of $\frac{7}{16}$ in. per foot. The drive is a 75-h.p. motor. The kiln, which was supplied by F. L. Smidth & Co., is lined throughout with refractory bricks, 40 per cent. and 50 per cent. alumina bricks being used except in the 40-ft. burning zone, where 70-per cent. high-alumina bricks are employed. The speed of the kiln is generally maintained at 78 revolutions per hour, and the rate of feed is automatically synchronised with the speed of the kiln. The fuel consumption is apparently about 80 lb. (about 1,000,000 B.T.U.s) per barrel.

While the economy of the kiln is due in considerable measure to its extreme length, the use of the latest type of air-quenching clinker cooler is also credited with a portion of the efficiency attained. This is an inclined-grate unit which recuperates part of the heat dissipated in the cooling process and returns it to the kiln with the secondary air. It is estimated that possibly 80 per cent. of the combustion-air in the kiln is represented by that recuperated through the cooler, the remainder entering as tempering air to the pulverizer and around the kiln hood. A thermocouple over the cooler grates regulates the temperature : volume ratio. Air in excess of that required for combustion passes up the exhaust stack on the cooler. The bituminous coal used has an average value of 12,500 B.T.U.s per lb. with a top size of $\frac{3}{16}$ in.

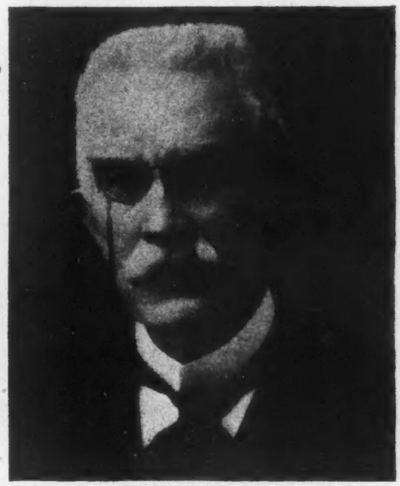
A New Cement Works in Iraq.

A NEW cement works having a capacity of 250 tons per day has recently commenced production in Iraq It is reported that difficulties in the despatch of cement from this works are being experienced because of the shortage of paper bags.

d'Henry le Chatelier.

The centenary of the birth in Paris of d'Henry le Chatelier occurred in October 1950. At the age of twenty-seven Le Chatelier became professor of chemistry at the School of Mines, and subsequently held several eminent academical positions until his death in September 1936. His principal interest was the association of scientific research with industry (especially as regards cement, mortar, and plasters) and thermodynamics. One of his earliest publications (1882) expounded a theory of the setting of cement and described his researches on the constitution of cement and mortars, which was also the subject of the thesis for his doctorate (1887). Towards the end of last century he published a description of the well-known

L. J. Vicat.



d'Henry le Chatelier.

and simple apparatus which he had devised, and which is still in use, for determining the expansion of cement upon hardening. Subsequently his researches included the heat-balance of rotary kilns, the effect of sea-water on cement, and the study of high-alumina cement.

One of the accompanying portraits is of Le Chatelier taken late in life, and the other is of the engineer L. J. Vicat who did much towards the development of artificial cements in the early years of the nineteenth century, and with whom Le Chatelier's maternal grandfather collaborated on research connected with these materials. Vicat was the inventor of the apparatus which is still in use for determining the setting-time of cement.

United States Standards for Cement.

THE latest standard specifications (up to May, 1950), methods of chemical analysis, and physical tests of the American Society for Testing Materials are now published in a volume of 224 pages entitled " A.S.T.M. Standards on Cement " (obtainable from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa. Price 2 U.S. dollars).

The specifications include Portland, air-entraining, blastfurnace, natural, and masonry cements. Specifications dealing with the flow-table and test sieves are included. The tests for Portland cement include tests for air-content, expansion in an autoclave, chemical composition, and heat of hydration. The determination of fineness by the air-permeability apparatus, by a turbidimeter, and by a No. 200 sieve is described. The method described for the determination of sodium oxide and potassium oxide in Portland cement is by flame photometry. The common tests of compressive and tensile strength, consistency, setting time, soundness, and specific gravity and methods of sampling are included. There is also a test for ascertaining the probable alkali reaction between the cement and aggregate, and a definition of the term " addition " as applied to hydraulic cement.

Supplementary information on analytical balances and weights, cement testing, and the methoxyl method of determining vinsol resin, and a short bibliography are given in appendixes.

Silicates in Portland Cement.

THE Department of Scientific and Industrial Research reports that its investigations on the high temperature chemistry of the silicates in Portland cement, which has been going on for many years, has been carried a step farther by the artificial preparation of single crystals of $3CaO.SiO_2$ large enough for X-ray and goniometric measurement, and these have been compared with those occurring in Portland cement. It is thought that this will open up a new path in the general investigation of the relation between the chemical constitution and physical properties of cements.

" Safety " Competition in Cement Works.

A " SAFETY " competition open to cement works in Great Britain and Northern Ireland has been inaugurated by the Cement Makers' Federation. Cement works are classified in divisions, and the works in each division having the lowest frequency rate of accidents each year will be deemed the winner. The award is a bronze plaque and, in addition, a challenge trophy will be held by the works having the lowest frequency rate. The first awards will be made at the end of 1951.

Whereas in the year 1927 there were 868 lost-time accidents at the works of the companies owning the largest group of cement factories in Gt. Britain, in 1949 there were 350 lost-time accidents.

A New Cement Works in Portugal.

A NEW cement works (*Fig.* 1) recently put into operation at Pataias, Portugal, by the Companhia Portuguesa de Cimentos Brancos Cibra, has an annual capacity of 60,000 tons. It is intended that white and other special cements only will be manufactured.

A plan of the works (reproduced from "Cemento Hormigon") is given in *Fig.* 2. The various parts of the works are as follows.— (1) Narrow-gauge tracks. (2) Limestone crushers having a capacity of 40 tons per hour. (3) and (4) Gyratory drier and chimney of drier. (5) Raw material store. (6) Raw-material crushers producing 17 tons of crushed material per hour with a maximum residue of 10 per cent. on a 4900-mesh sieve ; a current of air, which extracts the moisture

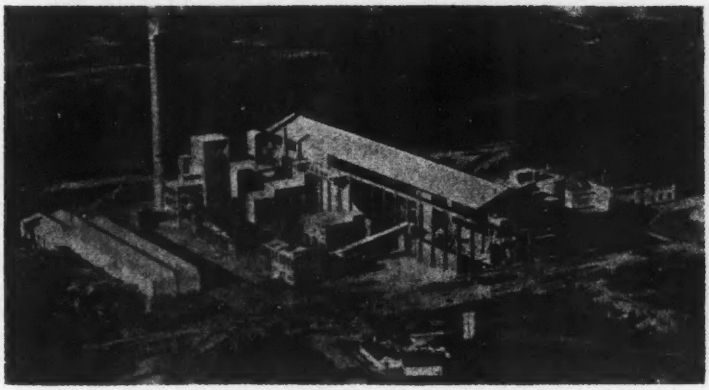


Fig. 1.

remaining in the limestone, enables the machine to work with material containing 2 per cent. of moisture. (7) Blending silos, the purpose of which is to reduce variations in composition of the ground materials, comprise two small bins each of about 50 cu. yd. capacity ; the materials are kept fluid by the infusion of air, and are agitated and mixed with material ground previously. (8) Two silos, having a total capacity of 1300 tons, for the storage of ground raw material, which is extracted by fluidisation induced by the infusion of air. (9) Rotary kiln 216 ft. long, 8 ft. 4 in. diameter in the clinkering zone and about 10 ft. diameter elsewhere ; the normal production is 170 tons per 24 hours but the kiln can produce 200 tons daily ; the kiln is fired with oil having a thermal value of 1250 calories per kilogramme. (10) Reinforced concrete chimney 215 ft. high. (11) Oil-firing apparatus and store. (12) Clinker transporter. (13) Clinker store. (14) Overhead crane. (15) Gypsum crusher. (16) Cement mill, which is 52 ft.

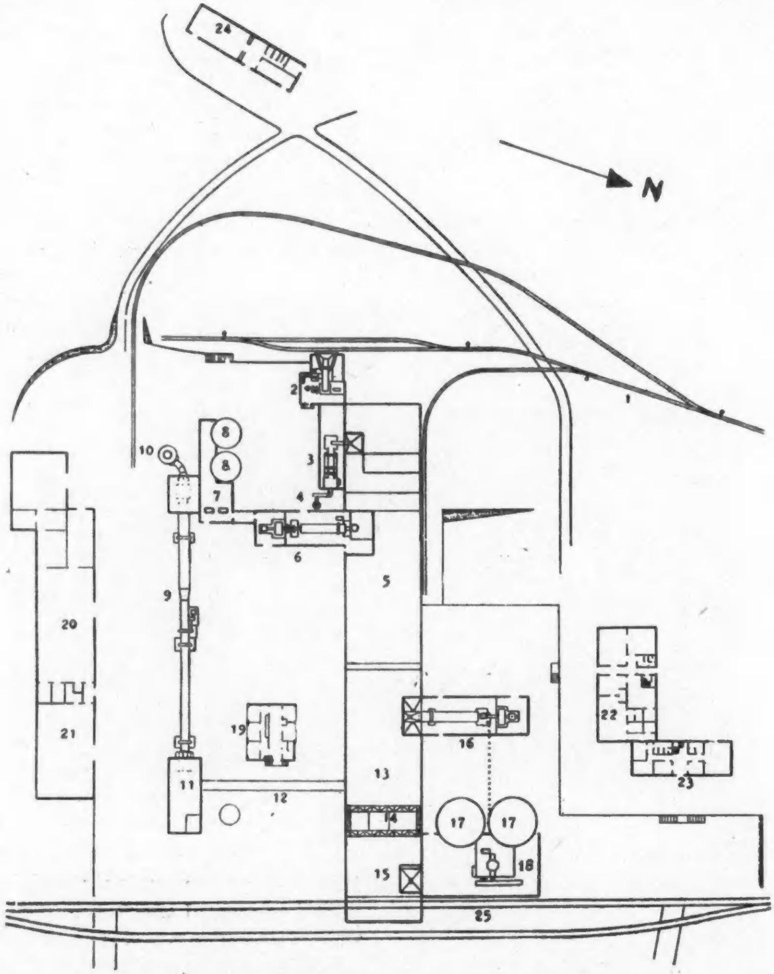


Fig. 2.—Plan of New Cement Works in Portugal.

long and 8 ft. 6 in. diameter, and can grind 11 tons of cement per hour to such a fineness that not more than 2 per cent. is retained on a 4900-mesh sieve. (17) Two cement storage silos of reinforced concrete each having a capacity of 3200 tons; the cement is transported pneumatically from the mill to the silos. (18) Cement-packing shed where in one hour 29 tons of cement can be filled into 1-cwt. bags. (19) Electricity substation. (20) and (21) Offices and stores. (22) and (23) Laboratory and offices. (24) Canteen. (25) Railway.

Defective Mortar and Concrete in Marine Works.

IN a report published recently by the Portuguese Ministry of Public Works, the results of an investigation of the condition of cement mortars and concretes at the principal ports in Portugal are described. In the north of Portugal, where granite aggregate is used, there is much defective concrete, while elsewhere concrete is in an almost perfect condition although about fifty years old. The granite is generally a coarse-grain material composed of two types of mica. The defects are principally that the mortar in joints of masonry exudes a white substance, becomes spongy, and eventually leaves the joint open, necessitating repointing about every five years. Defective concrete is cracked and is easily disintegrated. Analyses and tests of the materials used in the works and of samples taken from the structures are given, and the following conclusions are given in the report.

The hypothesis that the defects are primarily due to the action of sea-water on the cement is rejected although the presence of sea-water accelerates disintegration due initially to other causes. Generally, the cements used on works that are defective and constructed in the past twenty years are the same as those used on works showing no deterioration and constructed in the same period. The chemical composition and physical properties of the various cements are very similar and fluctuate little. The average compositions of the cements used on works at seven ports is : CaO, 64·1 to 65·2 per cent. ; SiO_2, 20·6 to 21·3 per cent. ; Al_2O_3, 5·73 to 6·70 per cent. ; Fe_2O_3, 2·67 to 3·46 per cent. ; MgO, 1·43 to 3·09 per cent. ; SO_3, 1·16 to 1·65 per cent. ; loss on ignition, 0·75 to 2·42 per cent. The average tensile strengths (in lb. per square inch) are : at seven days, 412 to 509 ; at 28 days, 430 to 533 ; at three months, 424 to 538 (the average tensile strength of cement used at most of the ports decreased between one month and three months) ; at six months, 454 to 533 (the strengths at six months and later apply to cements used at four ports only) ; at one year, 511 to 570 ; and at two years, 597 to 710. The average compressive strengths (in lb. per square inch) are : At seven days, 4623 to 7026 ; at 28 days, 5334 to 8164 ; at three months, 5761 to 8164 (at all the ports the average strength at three months exceeded that at one month) ; at six months, 5846 to 7823 (the strengths at six months and later apply to four ports only) ; at one year, 5988 to 8164 ; at two years, 6173 to 8363.

One analysis of the cement after the reaction occurring in a defective concrete was : CaO, 14·6 per cent. ; SiO_2, 23·6 per cent. ; Al_2O_3, 6·2 per cent. ; Fe_2O_3, 4·2 per cent. ; MgO, 45 per cent. ; SO_3, 4·2 per cent. ; this shows a remarkable decrease in the lime content but an alarming increase in the MgO-content.

It cannot be said that the mixtures of the mortars and concretes are deficient in cement. The quantity of cement in 1 cu. yd. of concrete showing the worst defects is from 500 lb. to 760 lb. In some defective mortars the quantity of cement is 850 lb. per cubic yard, but in other cases it is only 500 lb. per cubic yard and therefore may be a contributory cause of the defects.

Another contributory cause in two cases of defective mortar is likely to be the bad grading of the sand which has an excessive proportion of large grains. The mortar made with these sands is porous and even spongy. The existence of drainage holes through quay walls built in lean mortar may aggravate the defects because they enable sea-water to gain access to the mortar in the interior of the wall and to get behind the walls. The grading of the sand cannot, however, be a decisive factor because concrete elsewhere made with similar sand is not defective.

As the defective concrete and mortar is confined generally to the area where granite occurs, the primary cause is probably the interaction of the cement and the aggregates. Chemical analysis of a white paste exuded from some 90-ton concrete blocks suggests that some reaction between the aggregate and the alkalis in the cement was occurring because the silica-content of the paste was low. The view that cement-aggregate reaction is the primary cause is strengthened by the condition of the fractures of some broken blocks, the surfaces of which were in good condition. The good condition of some concrete in the granite region is attributed to the great care taken to obtain compact concrete, thereby confirming the common view that concrete in sea-water must be well made and dense.

Although the cause of the defects may be the cement-aggregate reaction, it is apparent that the defects are strongly influenced by the sea-water. It is important to note that in all the analyses of the cements in defective concrete there is an increase in the content of alumina.

Compression tests of the defective concretes confirm the observations, since the strength of the cubes decrease in course of time, whereas the strengths of the corresponding sound concrete increase. This shows that knowledge of the early strength of concrete is not a proof that it will continue to have the same strength. The following are the compressive strengths (in lb. per square inch) of the concrete of some of the works that have become defective. The strength of a concrete with 500 lb. of cement per cubic yard increased from 2503 lb. at seven days to 4295 lb. at 28 days, but at three months it was 3741 lb. The strength of similar concrete at another port showed little change between seven days and one year. The strength of concrete with 600 lb. of cement per cubic yard was the same at one year as at seven days, although at three months the strength exceeded by 40 per cent. the strength at seven days. A decrease in strength after three months was common to all the defective concretes, although sound concretes with the same cement content increased in strength up to two years and in some cases up to five years and ten years.

Cement Machinery for the Belgian Congo.

THE Commercial Department of the British Embassy at Brussels reports that "Cimenterie d'Albertville-Cimental," with a capital of Frs. 40 million, has been formed with the principal object of exploiting limestone deposits near Kabimba Bay on Lake Tanganyika, and to produce chalk and cement from the limestone quarried. It is understood that the company wishes to receive catalogues and technical literature from United Kingdom manufacturers of machinery and supplies for cement factories. Catalogues should be sent to Monsieur Freys, Cimenterie d'Albertville "Cimental," 112, rue du Commerce, Brussels.

Gypsum in Portland Cement.

IT has been shown, notably by Mr. W. Lerch*, in 1946, that there is an optimum gypsum-content for each type of cement which results in the greatest strength, least shrinkage upon drying, least expansion upon wetting, and early hydration. The optimum amount of SO_3 is found to be higher for a cement of high alkali-content and for a cement containing a large calculated amount of C_3A. Great fineness is also shown to increase the optimum amount of SO_3 for a cement of high, or moderately high, C_3A-content. As a result, American standards were revised to increase the maximum of SO_3 content by 0·5 per cent. when the cement contains more than 8 per cent. (calculated) of C_3A, but it has been suggested that even this increased content of SO_3 may be low, with the result that manufacturers are possibly restricted in their efforts to secure maximum early strength and least volume changes. In Mr. Lerch's opinion a minimum limit of SO_3-content (in addition to the maximum limit) might be beneficial to ensure the production of properly regulated cement. The report of a committee appointed by the American Society for Testing Materials to consider the problem of the optimum amount of gypsum in Portland cement is given in the " A.S.T.M. Bulletin " for October, 1950.

Eight Portland cements of Types I, II, III, and IV (American Standards) and of high and low alkali-content were examined. Type V (high sulphate-resistance) was considered to be represented by Type IV. Each cement was prepared with seven different amounts of natural gypsum to provide SO_3-contents in increments of 0·5 per cent. from 1 per cent. to 4 per cent. (except for Type III rapid-hardening cement, which contained 2 per cent. to 5 per cent.), and was ground to a specific surface of about 1,900 square centimetres per gramme. Rapid-hardening cements were ground to a specific surface of about 2,100 and 2,600 square centimetres per gramme. The samples of cement were: (1) Type I, ordinary, high-alkali; (2) Type I, ordinary, low-alkali; (3) Type II, moderate sulphate-resistance and moderate heat of hydration, high-alkali; (4) Type II, moderate sulphate-resistance and moderate heat of hydration, low-alkali; (5) Type III, rapid-hardening, high-alkali; (6) Type III, rapid-hardening, low-alkali; (7) Type IV, low heat of hydration, high-alkali; and (8) Type IV, low heat of hydration, low-alkali.

Physical Properties.

The results of the physical tests are discussed as follows:

All cements had exceptionally low expansion in the autoclave, but expansion generally decreased as the SO_3-content increased. High-alkali cements of Types I, II, and IV entrained considerably more air than did the corresponding low-alkali cements. No significance is attached to this difference except as it affects durability in freezing-and-thawing tests. The amount of water required for normal consistency and for plastic mortar increased slightly with increase of gypsum. The initial and final setting were delayed as the gypsum content

* See this journal for September, 1946, p. 92.

increased, except for cement No. 6. The rate of heat liberation failed to indicate clearly the optimum gypsum-content except for cement No. 2, in which case the optimum was 2·5 per cent. to 3 per cent. of SO_3. For all cements, the 24-hours' cumulative heat of hydration was found to correlate well with other criteria, the greatest heat occurring at the optimum SO_3-content, which therefore provides an indication of the SO_3-content for the greatest 1-day strength since heat of hydration and strength are closely related at early ages. The greatest strength was developed with a particular SO_3-content, although the amounts required to give the greatest strength at different ages were not always the same.

From consideration of all the data, optimum SO_3-contents were selected for each cement, and these are given in *Table* I. In each case the high-alkali cement requires from 0·5 per cent. to 1·0 per cent. more SO_3 for greatest strength than does the corresponding low-alkali cement. The amount of SO_3 producing the greatest bending strength is also given in *Table* I, and, in general, is nearly equal to that which gives the greatest compressive strength.

TABLE I.—OPTIMUM SO_3-CONTENT (PER CENT.)

Cement	Type	For least contraction	For least expansion	For greatest compressive strength	Greatest bending strength	Optimum heat generation	Average of preceding criteria	Extraction test
No. 1	I, high C_3A, high alkali	3·5	3·0	3·5	3·0	?	3·5	3·0
No. 2	I, high C_3A, low alkali	3·0	2·5	2·5	2·0	3·0-2·5	2·5	3·0
No. 3	II, high alkali	3·0	2·5	2·5	2·5	?	2·5	2·5
No. 4	II, low alkali	2·0	2·0	2·0	2·5	?	2·0	2·0
No. 5	III, high alkali	4·5	3·0	4·0	4·5	?	4·0	3·5
No. 6	III, low alkali	3·5	2·0	3·0	3·5	?	3·0	3·5
No. 7	IV, low C_3A, high alkali	3·5	3·5	3·0	3·0	?	3·5	3·5
No. 8	IV, low C_3A, low alkali	1·5	2·0	2·5	1·5	?	2·0	2·0

Expansion and contraction tests made on plastic-mortar prisms, 1 in. square by $11\frac{1}{2}$ in. long (10 in. gauge length), showed that distinct minimum expansion and contraction occurred for each cement, and the optimum SO_3-contents for least expansion and contraction are shown in *Table* I. Large expansion due to wetting, and increased contraction due to drying, may occur if gypsum is added in quantities in excess of the optimum, but the optimum quantities indicated are generally much greater than the maximum amount of SO_3 permitted by current specifications. It is considered that if the optimum SO_3-content is used, cement of greater constancy of volume should result.

Extraction Test.

A performance test was made of the finished cement to show whether it actually contained the optimum amount of gypsum. This test is considered to be necessary as the results of the criteria tests are not entirely suitable for specification purposes; it also has an advantage over arbitrary chemical limits in that it is easier to satisfy users and manufacturers. The extraction test proposed as a possible specification performance test determines the presence or absence of gypsum in pastes or mortars that have hardened in a moist room at 70 deg.F. for 18 hours and 24 hours. The test is based on the relative SO_3-concentration of a solution saturated with

calcium hydroxide and calcium sulphate or sulpho-aluminate. In the absence of alkalis, the SO_3-concentration of a solution saturated with both gypsum and calcium hydroxide is approximately 1 gramme per litre whereas, after the gypsum has become depleted, a solution saturated with calcium hydroxide and calcium sulpho-aluminate has an SO_3-content of less than 0·01 gramme per litre. In the presence of alkali, the SO_3-concentration of the saturated lime-gypsum solution may be several grammes per litre. However, after the gypsum has become depleted, the effect of alkali on a solution saturated with lime and sulpho-aluminate is small. For the ordinary alkali-content of Portland cement, the SO_3-content of such a solution will not exceed 0·07 gramme per litre. Therefore, if the extract obtained from the hardened paste or mortar contains more than 1 gramme of SO_3 per litre, it is evident that the gypsum was not depleted during the period of curing, but if the SO_3-concentration is less than 0·07 gramme per litre it is evident that the gypsum was depleted. Practical limits are that an extract should not yield more than 0·2 gramme of SO_3 per litre at 18 hours or less than 0·5 gramme per litre at 24 hours. With these limits the optimum quantities shown in *Table* I correspond very closely with the average obtained from the criteria tests.

Durability.

The procedures used for determining durability varied widely, so that it is difficult to compare the results. Generally the optimum SO_3-content determined by the criteria tests is slightly above the SO_3-content for greatest durability. In the presence of air-entraining agents, however, the differences in durability due to varying SO_3-content appear to be negligible. The cements of high alkali-content showed generally better durability than did low-alkali cements of the same type, but high-alkali cements of Types I, II, and IV entrained considerably more air than did the low-alkali cements of these types. It is probable that the greater air content explains in part the greater durability of the high-alkali cements.

Conclusions.

Giving most weight to the optimum established by compressive strength, expansion, and contraction, an average to the nearest 0·5 per cent. for all criteria is given in the penultimate column of *Table* I. The optimum determined by the extraction test, as given in the last column, agrees with the average of the various criteria for half the cements, and disagrees with the remainder by only 0·5 per cent. In every case the high-alkali cement needs more gypsum than the low-alkali cement of the same type, the difference being as much as 1·5 per cent. Type III cement with a high-alkali content requires the greatest optimum amount of gypsum and next in order is Type I high-alkali cement ; surprisingly, Type IV high-alkali cement seems to require almost as much. The data agree with Mr. Lerch's conclusion that low-alkali cement of high tricalcium-aluminate content requires larger additions of gypsum than those of low tricalcium-aluminate content. Types II and IV low-alkali cements do not have as high an optimum SO_3-content as Types I and III low-alkali cements.

It is evident from these data that, if advantage is to be taken of the improvement which optimum gypsum-content affords, specifications must permit a higher limit of SO_3. Increases of 1 to 2 per cent. beyond the present limits are indicated. The tests show that cements of greater constancy of volume can be obtained by using an optimum amount of gypsum, and, unless the optimum amount is greatly exceeded, there appears to be little risk of excessive expansion which is apparently the only reason for specifying maximum limit of SO_3.

Proposed New Cement Works in Malaya.

A NEW company, known as Malayan Cement, Ltd., has been formed with the object of building a cement works at Rawang, Selangor. The company, which has a capital of ten million dollars, has been formed jointly by the Associated Portland Cement Manufacturers, Ltd., of London, and Malayan Collieries, Ltd.

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